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THE ROLE OF RESEARCH IN MANNED SPACE FLIGHT

by

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Lecture to Santa Clara County Science Teachers
Ames Research Center
October 22, 1964

This country's plan to land American explorers on the moon is part of a step-by-step process we are undertaking in our determination to be the leading spacefaring nation. The achievement of this goal will give a tremendous boost to science and technology and will increase our prestige and security. It is a goal everyone can understand as it provides adventure and exploration in the best American tradition.

The moon landing is a very difficult but attainable goal. It is attainable because we have on hand a broad foundation of flight science and technology to make it a success. This foundation was achieved through years of research by government, universities, and industry.

ARPA

The Ames Research Center, with its team of scientists and engineers under the direction of Dr. Smith J. DeFrance, has been making contributions to the science of flight for almost a quarter of a century. It is this type of contribution and dedication that provides us the stepping stones to the moon. You will learn of some of this work in the succeeding lectures of this course.

During the span of Ames' existence, there has been a great surge of research and development across the country. In 1940, this country spent 345 million dollars in research and technological development, often called R&D. Today, it is estimated that the total R&D budget will soon exceed 20 billion dollars -- almost a sixty-fold increase! This incredible growth follows an exponential law which we find in living systems in which there are no artificial constraints. In other words, the growth is proportional to the amount of science and technology that already exists. For the past decade, the growth has been at a rate of 15 per cent per year. This doubling of science and technology every five years is far outstripping other growth rates. The output of Ph.D.'s in this country is doubling every ten years. The gross national product is doubling every 20 years, and the world's population is doubling every 50 years. It is little wonder that such growth has been termed "explosive" and that the twentieth century is being called the period of the Scientific Revolution.

The high rate of growth, however, cannot be maintained indefinitely. If it were, the annual expenditure in ten years would be close to the level of the present total Federal budget! Congress is taking an increased interest in this rapidly expanding area of R&D and there are indications that we may be approaching a leveling-off period.

The mighty force of research has produced profound changes in our economic, social, and political life. Drug firms, which spend as much as ten per cent of their total sales on research, are marketing a large variety of medicines that were unheard of ten years ago. Electronics has advanced in a spectacular manner. The vacuum tube was developed and refined over a fifty-year period, but in less than ten years the transistor is making the tube obsolete in many electronic applications. Thin-film techniques and integrated circuitry allow the building of complex circuits into tiny blocks. The laser promises even more electronic wonders. It has been only twenty-two years since Fermi and his group of scientists and engineers in Chicago produced the first self-sustained chain reaction in a nuclear reactor. Today we see the beneficial effects of this energy source in the fields of medicine, agriculture, industrial processes, electric power generation, and propulsion. Ten years after we began concentrated work on guided missiles, we see them replacing the aircraft as our primary long-range weapon.

Four years after our first satellite launching we placed John Glenn in orbit and within eight years from his flight, we expect to place American explorers on the moon's surface and return them safely to earth.

I read with great interest the other day about the preparation of a time capsule, to be buried for the enlightenment of some future archaeologist. It is to contain those things most representative of our age. Among the artifacts were: antibiotics, pyroceram, computer memory units, plastic heart valve, super-conducting wire, ruby laser rod, normal and irradiated seeds, desalted seawater, permanent magnet, birth control pills, transistor radios, freeze-dried foods, electric toothbrush, and tranquilizers. I think that is a good cross sampling and shows eloquently the impact of science and technology on our lives.

Some of our modern devices are really very old ideas that have awaited some key development before reaching a high state of usefulness. The turbojet engine, which has brought a significant increase in aircraft speed, is an example. The principle of the turbojet was known for many years, but materials limited the temperature to such low values that the engine could do little useful work for almost all the energy went into driving the compressor. With the development of heat resistant materials, the operating temperature was increased until the engine has virtually displaced the piston engine in large aircraft transports. In the same manner, better materials hold the key to increased engine performance and decreased structural weight of supersonic transports. Our research shows that a safe and reliable supersonic transport is technically feasible now, but additional research is needed to make it economically attractive. The gains to be made by improved materials as well as improvements in several other areas are illustrated by my first slide (R64-376).

A supersonic transport with 35,000 pound payload -- about 150 passengers and 3,650 pounds of cargo -- has been chosen. The figure illustrates that with present technology, a 400,000 to 500,000 pound airplane is required to achieve a range of approximately 2,500 to 3,000 nautical miles. With additional research, the maximum range can be extended to 3,500 nautical miles, or greater than 4,000 statute miles with gross weights of 350,000 to 450,000 pounds. Thus, supersonic transports built with this improved technology will cost less, operate at lower cost, and, because of their lower weight, have a lower sonic boom intensity than those using today's technology.

The NASA is working on these problems as well as other advancements in aeronautics at its four Research Centers: namely, Ames; Lewis at Cleveland, Ohio; Langley at Langley Field, Virginia; and Flight at Edwards, California.

An even better example, than a turbojet, of a modern device with a long history is the rocket engine. The Chinese, in the Thirteenth Century, were the earliest known developers of rockets and, it is said, an early Chinese made an unsuccessful bid for space travel by lashing a group of rockets to his chair and having his servants ignite them! The rocket idea soon spread to Europe and it rose to prominence as a weapon until the Nineteenth Century. It underwent several technological developments. Congreve improved its accuracy by adding a stabilizing wood stick. Hale improved the accuracy by spin stabilization, but his idea was applied to cannon shells by means of rifling the barrel, and this made the rocket obsolete. It remained so until modern engineering was applied twenty years ago and the world was startled by the spectacular performance of the V-2 rocket. The development of guided missiles in this country gave us the necessary technology to reach satellite velocities and travel in space became a reality.

Our first launch vehicles, with the exception of Vanguard, were based on military missiles. Modifications have been made to the missile for space use and upper stages have been added. The present group of light and medium launch vehicles used by the NASA is illustrated in the next slide (PT63-1937).

The Scout is a three-stage, all-solid booster built especially for space use. Delta and Thor-Agena use the Thor missile as the first stage. The Delta has two upper stages originally designed for the Vanguard. The Agena upper stage is used on top of both the Thor and Atlas missiles. Centaur is a modified Atlas, plus a new hydrogen-oxygen upper stage still in development. Payloads in earth orbit range from 240 pounds to 8,500 pounds, and in an earth escape trajectory, from 100 pounds to 2,300 pounds.

One of the first realizations facing this nation's space planners after the spur of Sputnik was the weight-lifting limitations of our missiles that were developed for comparatively small and efficient nuclear warheads. A key to increased weight carrying capability was the rocket engine. We needed not only higher thrusts, but also more efficient engines; that is, engines that develop high thrust per pound of propellant exhausted in a unit of time, called specific impulse. Accordingly, several major and bold national decisions were made that were based on research conducted over the previous five years. One was to start immediate development of an engine of 1,500,000 pounds thrust, ten times greater than the largest single thrust chamber at that time. Another was the decision to use liquid hydrogen as a fuel in new upper stages. Dr. Abe Silverstein, of the Lewis Research Center, played a key role in these decisions, and I am proud that I was a contributor to the extensive work on hydrogen at Lewis that led to its choice. The engine series started in the early days and since augmented as shown by the next slide (M63-435).

The A-3, started in 1958, was the first rocket engine using oxygen-hydrogen to be developed for vehicle use. It delivers 15,000 pounds, has a specific impulse of about 430 pounds thrust (lb./sec.) and is very successful. The A-3 powers the upper stage of the Atlas-Centaur vehicle and the second stage of the Saturn I vehicle.

The H-1 engine, which grew out of the missile program, is a simplified, highly reliable engine using oxygen-kerosene, and developing 188,000 pounds thrust. The F-1 engine, started in 1958, develops 1.5 million pounds thrust and uses oxygen-kerosene. The J-2, started in 1960, develops 200,000 pounds thrust, using oxygen-hydrogen. The latest start, in 1962, is the M-1 engine, using oxygen-hydrogen, and developing 1.5 million pounds thrust. These engines give us the power and efficiency needed for our trip to the moon, and all except the M-1 play a role in the Apollo program.

Another early decision was to build large boosters and thus, the Saturn series was started. These are illustrated by the next slide (AA63-27), where they are compared with the Statue of Liberty in size. Saturn I uses eight H-1 engines in its first stage, for 1.5 million pounds thrust and six A-3 engines in its second stage for 90,000 pounds thrust. There have been seven flights and seven successes. Last January, about six years after the 40-pound Explorer, Saturn I placed over 1,900 pounds in orbit. Saturn I-B is an up-rated version of Saturn I with an upper stage using the new J-2 engine previously mentioned. It will be able to place over 30,000 pounds in earth orbit. The largest of the series, and the one used for Apollo, is Saturn V, 361 feet tall with its spacecraft. A better view of Saturn V is shown by the next slide (M63-423).

The first stage consists of five F-1 engines, developing 7.5 million pounds thrust, the second stage, five J-2 engines of one million pounds thrust, and the third stage, one J-2 of 200,000 pounds thrust. The total payload capability for a lunar mission is 90,000 pounds.

Concurrent with the build-up of booster capability has been development of spacecraft to carry men into space (AA63-23). The Mercury program was started within a week of the formation of NASA. The Mercury program was based on research results obtained at our Langley and Ames Research Centers. The group that planned and carried out the six historic man flights was formed from men engaged in aeronautical and missile research. This has been the basic plan of NASA from its beginning. At the heart of our management method, we find direction not by professional managers, but by professional scientists and engineers who are themselves engaged in work at the boundaries of their science and technology.

The Mercury project showed that our design approach was sound and that man can fly in space and return safely. Gemini is a program to extend this capability by placing two men in space for periods of one to two weeks. During this period, they will test rendezvous techniques with an unmanned Agena spacecraft. Radar will locate the Agena at a distance of 200 to 250 miles, and Gemini will approach at a differential speed of 100 miles per hour while orbiting at a total speed of 17,500 miles per hour. When within 20 miles, the astronaut will home in on a flashing beacon on the Agena. When the two vehicles are very close, the astronauts will dock with the Agena at a one-mile-per-hour differential speed.

One major manned program is, of course, Apollo. Preliminary plans and discussions began a few months after Mercury was started, when results of studies at our Research Centers showed that a moon landing was feasible. Former President Kennedy made it a national goal on May 21, 1961. In its planning, NASA proceeded with caution, assessing problem areas, examining various alternative methods, weighing them and adding to its own judgment that of other groups in and out of government. The present plan was truly a national decision and one we are confident can meet the time goal if adequate support is maintained.

The Apollo spacecraft is shown by the next slide (M63-580). It has three major parts, the command module, the service module, and the lunar excursion module, or LEM. Atop the command module is a launch escape system to carry the spacecraft away from Saturn V should an emergency arise during launch.

On the momentus day of the first flight to the moon's surface, the three astronauts will be using the results of almost a decade of concentrated effort which include knowledge, skills, and equipment of 30,000 people in ten NASA Centers and over a quarter of a million people in more than 5,000 companies. They will have flight experience in space 100 times longer than the total time logged in Mercury. They will have the knowledge gained by dozens of unmanned satellites that have probed space about the moon and beyond. They will have the result of Ranger photographs of the lunar surface plus more detailed surveys made by lunar orbiting and the Surveyor lunar lander.

At the launch signal, the five giant F-1 engines will lift the 6 million pound vehicle away from the ground, and the trip will begin. Two-and-a-half minutes later, the first stage will stop and separate. The second stage will operate six-and-a-half minutes, and separate. The third stage will operate for about three minutes, then stop as the astronauts will then be in an orbit about the earth called a parking orbit. At this time, various systems are checked and this may take several hours. If all is well, the third stage is re-started and after about five minutes of operation, the spacecraft is on a lunar trajectory. At this time, the spacecraft undergoes a maneuver to move the lunar excursion module from its position below the service module to a position in front of the command module. This new position is shown by the next slide (PT63-1933). As they approach the moon after the 70-hour transit time, small control motors will orient the spacecraft and the 22,000 pound thrust service module engine will operate to slow down the spacecraft until a lunar orbit (90 miles above the surface) is achieved. Two astronauts then enter the lunar excursion module (as indicated in this illustration), separate from the command module for the descent to the lunar surface. The

10,000 pound thrust descent engine will start and operate first to get into an orbit within ten miles of the surface and then, at thrusts varying from 10,000 to 1,000 pounds, will land gently on the lunar surface.

After a period on the moon lasting from several hours to as long as a day, the astronauts will operate the ascent engine of 3,500 pounds thrust and rise into an orbit to bring it close to the command module, and docking will complete the rendezvous. The command module, with its remaining astronaut, is also capable of the same docking maneuver, if necessary. After the two returning astronauts leave the lunar excursion module, it is abandoned in its orbit about the moon. The engine of the command module is operated to leave the lunar orbit and the return trip to the earth begins. The navigational aim for this return must be accurate -- like shooting the nap off a tennis ball at 100 yards without hitting the ball. If they approach the atmospheric mantle too high, they will zoom through without appreciable deceleration and on to an unwanted space voyage. If they dip too quickly into the atmosphere, their spacecraft may disintegrate. If the approach is correct, they decelerate through the atmosphere, parachutes are deployed, and they land. The elapsed time -- eight to ten days.

But already, six years before this event, we are laying the groundwork for other steps by research in a broad front. We plan to send unmanned probes to the near planets Mars and Venus. Our lunar and earth orbit work will teach us how to live in space for long periods. For man to travel to the planets, however, a more efficient transportation system than chemical rockets is needed. Nuclear propulsion will provide this capability and a large share of research effort is going into this propulsion method. The first type is the thermal nuclear rocket in which hydrogen as a working fluid is heated by passage through the nuclear core. Work on this method is proceeding very satisfactorily -- three successful hot reactor operations were conducted this year under joint AEC/NASA sponsorship.

A concept of a Mars spaceship, using nuclear propulsion, is illustrated by the next slide (RN64-388). It is a rather complicated spacecraft with several stages and might weigh as much as two million pounds in earth orbit. The assembly of such a spacecraft by uprated Saturn V's would require seven to eight flights, or the use of a new launch vehicle having an earth orbit capability of one to two million pounds. The nuclear rocket is used to depart earth orbit for Mars and to decelerate into a Mars orbit. Conventional chemical-fueled rocket would be used to descend to the Martian surface and return to the mother ship. Nuclear propulsion would then propel the voyagers back to earth. Such a trip is not envisioned before the 1980's at the present level of research.

Thermal nuclear rockets produce about twice the specific impulse of chemical rockets, or 900 to 1,000 pounds thrust/(lb./sec.) flow. If, instead of a solid core, a vortex gaseous core reactor is used, the operating temperature could be much higher. Such a system might increase specific impulse 2.5 or more times over the present solid core method. Gas core reactors are not new, but like other advanced concepts, they have many difficult problems that must be solved before they become useful. This is just the sort of challenge a research man likes.

Still another type of propulsion under study is nuclear-electric rockets. The nuclear energy is first converted to electrical energy, and this is employed to accelerate a working fluid to very high velocities. In some cases, the electrical energy heats the working fluid thermally by an electric arc.

In other cases, the fluid is accelerated by forces which are induced by electromagnetic or electrostatic fields. A schematic diagram of a nuclear electric system for spacecraft propulsion and position control is shown by the next slide (RN64-389).

The reactor, turbo-electric system and electric power regulation comprise the system to convert nuclear energy to electric energy. The electric power operates the ion engine, which consists of a thrustor, its control, and propellant feed system. Typical thrust values for ion engines, or clusters of them, range from 1/1000 of a pound thrust to values as high as 100 pounds. The electric power generation components represent by far the predominant weight of the system and are the primary reason for very low thrust-to-weight values -- on the order of 1/10,000 to 1/1,000,000. Such propulsion systems are of use only in applications where very low accelerations and long trip times do not limit the mission. An interesting possibility is a mission to the other planets, because their propellant consumption is very low -- on the order of a tenth or a twentieth of that of a chemical propulsion system. We have flown experimental electrical thrustors successfully, but much more research is necessary before they become of practical use.

The present limitation is getting electrical power generation systems that are light, reliable, and that operate for several years. Such systems are needed not only for electric propulsion but to provide electrical power for extensive lunar or planetary operations. One such system in the research stage at the Lewis Research Center is the SNAP-8 power generator system, an illustration of which is shown by the next slide (R63-598). It consists of a nuclear reactor which heats a sodium-potassium working fluid which, in turn, heats mercury in a heat exchanger. The hot mercury vapor drives a turbine which in turn drives a generator. The large corrugated-like cylinder is the radiator that rejects the waste heat of the mercury. The radiator is large, comparatively heavy and vulnerable to penetrations by micrometeoroids. We have a large research effort on this system and expect to test an experimental system soon.

Other types of electric power generating systems are being studied for a variety of operations. In chemical energy systems the battery, fuel cell, and chemical engine are being investigated. In solar energy systems, thermionic power generation, thermal engine cycles, and solar cells are all receiving attention. For example, conventional solar cells are adversely affected by radiation. Research on improved types have increased their radiation resistance an order of magnitude. One of the most promising research areas of solar cells is the thin-film cell, an illustration of which is shown by the next slide (R63-972). Conventional solar cells are single crystals usually about one or two centimeters wide, and two centimeters long, and about 20 thousandths of an inch. By new techniques, thin-film cells on flexible substrates with a three thousandths of an inch thickness appear possible. This would allow carrying large solar cell areas in a roll on a spacecraft for unfurling in space.

Since such thin films now exhibit low efficiencies, increasing efficiency and devising construction techniques are research goals.

Thus far, I have touched only on the energy conversion aspects of our research. There is work under way in materials and structures, in guidance, navigation, and communication, in life support and human factors, and other aeronautical areas than the supersonic transport work previously mentioned. Subsequent speakers will go into some of these areas in detail. I have, however, a film clip of a few typical research projects that I wish to show you now. (Film clip describes zero gravity fluid experiment, X-15 flight, Project Fire, and space suits.)

I would like to close with a few comments on transfer of information and on education.

The increased pace in research and technology has brought with it a flood of new information that must be communicated, analyzed, and assimilated. In its 380-orbit lifetime, Nimbus I produced 27,000 sharp weather photographs. The Tiros program has transmitted from space almost 400,000 pictures so far in its four-and-a-half years of operation, serving our weather forecasters even while developing a true space weather system. Data flows into our Goddard Space Flight Center, NASA's chief center for the collection of data from space, at the rate of 55 million data points per day. The volume may rise to 200 million points per day by next year. Large data inflow requires new, rapid data processing and compression methods and these are being developed. One example of research in the area is the automatic pattern recognition system shown by the next slide (RE64-380). This is an electronic technique to recognize significant weather indicators from the pictures taken by a Tiros or Nimbus satellite. Another example of rapid data handling is the testing of the giant Saturn engines. The data are transmitted by microwave from the test site to the computer so that by the time the test engineers return to their office after a run, the printed results are on their desks.

In addition to the processing of large amounts of data, we are also faced with a need for better communication of the results to others who can use them. There are certainly plenty of reports. It has been estimated that the world's laboratories are producing technical papers at the rate of 60 million pages per year. Space activities produce about a million pages of technical data a year. One wag has said that if our rockets fail, we could make a pile of all the papers generated by the space effort and simply climb to the moon.

The field of cybernetics offers hope in this communication traffic jam. The Center for Communication Sciences at M.I.T. is bringing together engineers, mathematicians, linguists, and neurophysiologists in a massive multi-discipline attack on the problem.

The rapid changes in science and technology require continued education to keep up with developments. A. C. Monteith has calculated that the "half life of today's graduate engineer is ten years -- i.e., half of what he knows will be obsolete in a decade." Monteith adds that half of what an engineer needs to know in the next ten years is not available to him today. Dr. R. L. Bisplinghoff has said that, "It is likely that even an initially well-educated professional will have to devote as much as 20 per cent of his time to continuing education to stay on top of his field."

As Dr. Glen Seaborg put it, "We are all swept up by the tide of discovery that is the scientific revolution." Although the rate may change, the growth of science and technology is essential to our way of life, and this gives us an unprecedented opportunity to help mankind everywhere.

In closing, the teacher, the scientist, and the engineer must be adaptable to the changes in science and technology brought on by their contributions. They must stay abreast of new developments and devise better ways of disseminating and assimulating the growing mass of knowledge. The teacher has the additional responsibility of equipping the pupil not with practices or procedures that will be outmoded quickly, but with the basic scientific and engineering tools that he needs to adjust to the rapid changes and to thrust forward for new contributions.

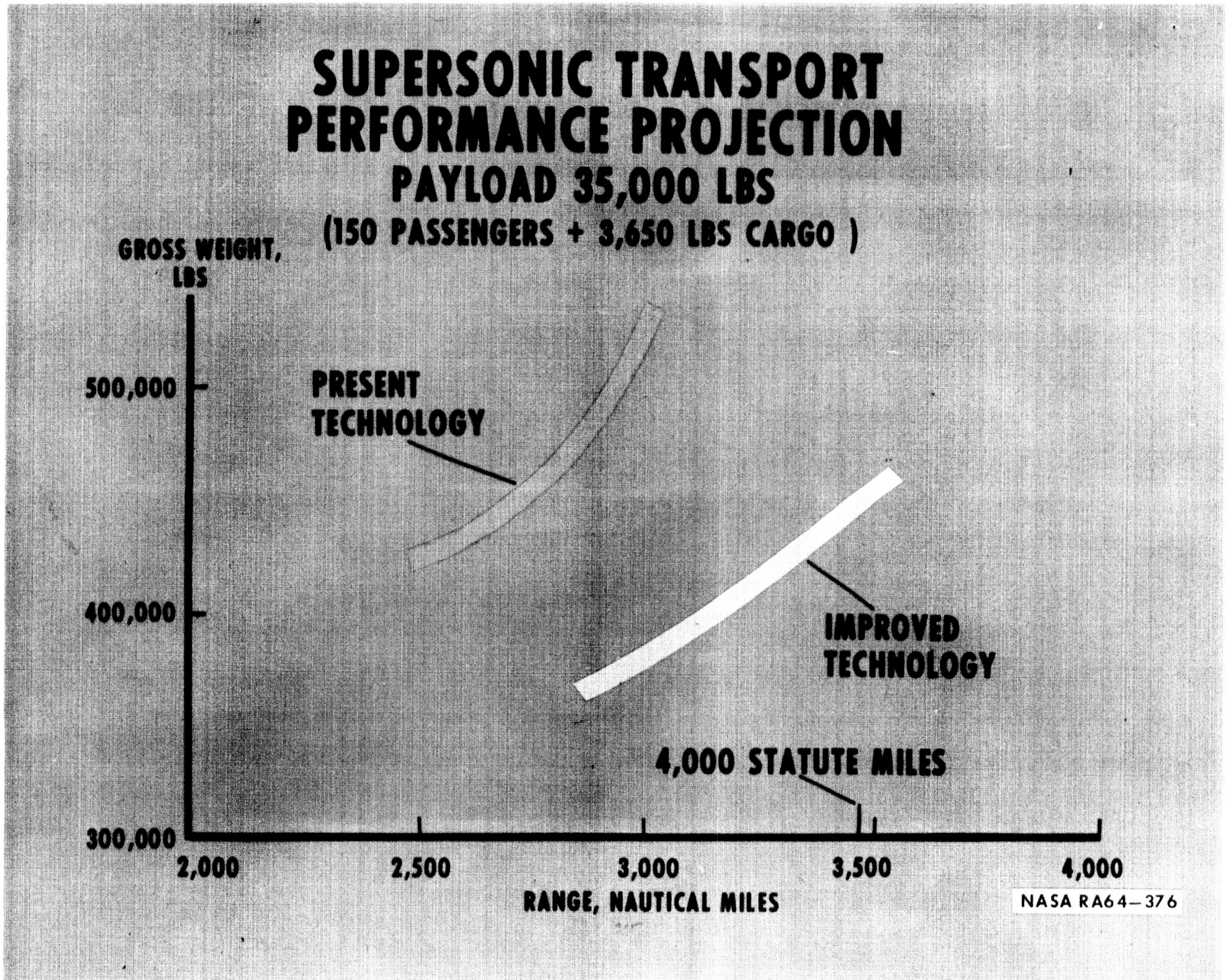
SUPERSONIC TRANSPORT
PERFORMANCE PROJECTION
PAYLOAD 35,000 LBS
(150 PASSENGERS + 3,650 LBS CARGO)
GROSS WEIGHT, LBS
500,000
400,000
300,000
PRESENT TECHNOLOGY
IMPROVED TECHNOLOGY
4,000 STATUTE MILES
2,000
2,500
3,000
3,500
4,000
RANGE, NAUTICAL MILES
NASA RA64-376

Figure 1

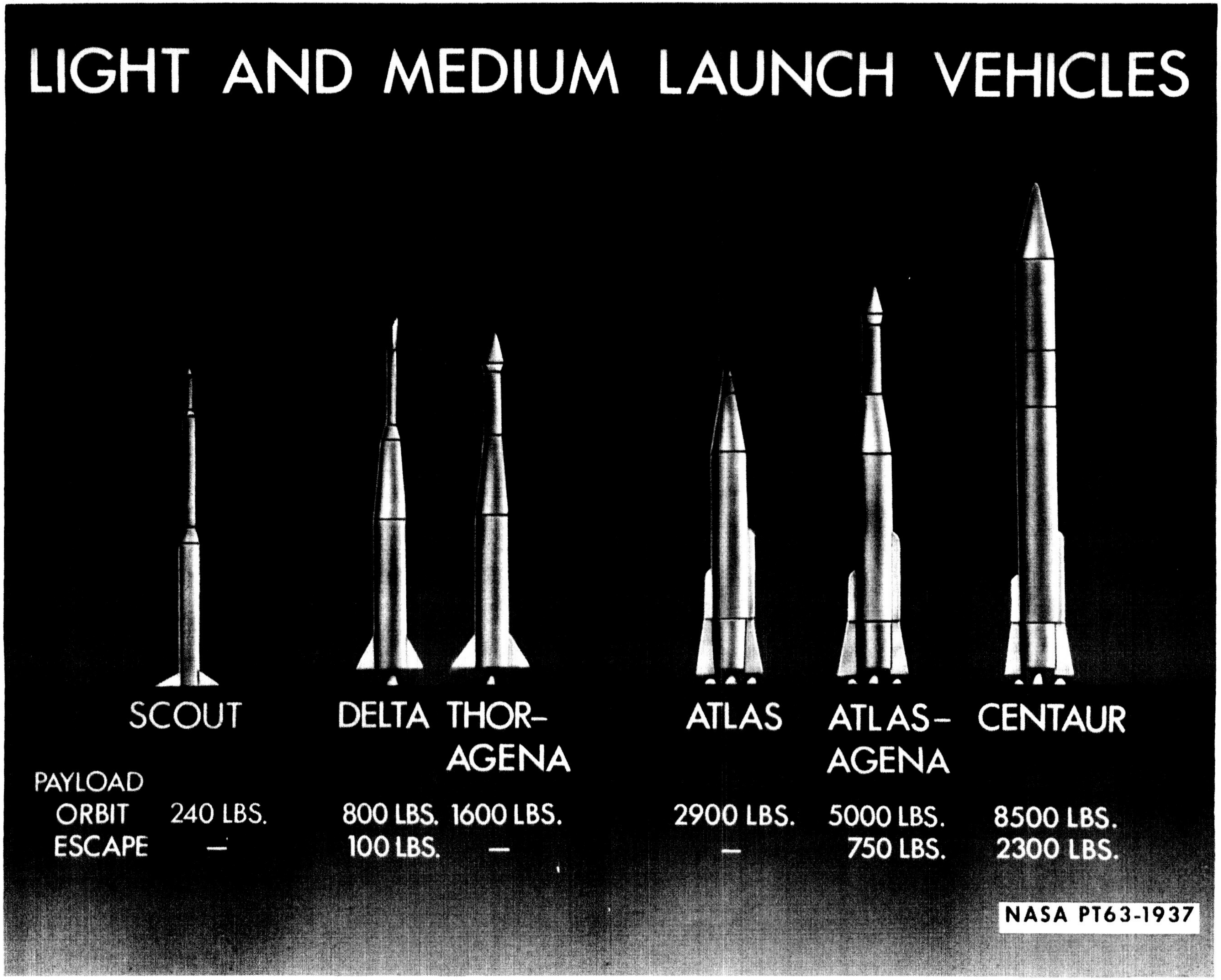
LIGHT AND MEDIUM LAUNCH VEHICLES
SCOUT
DELTA
THOR-AGENA
ATLAS
ATLAS-AGENA
CENTAUR
PAYLOAD
ORBIT 240 LBS. 800 LBS. 1600 LBS. 2900 LBS. 5000 LBS. 8500 LBS.
ESCAPE — 100 LBS. — — 750 LBS. 2300 LBS.
NASA PT63-1937

Figure 2

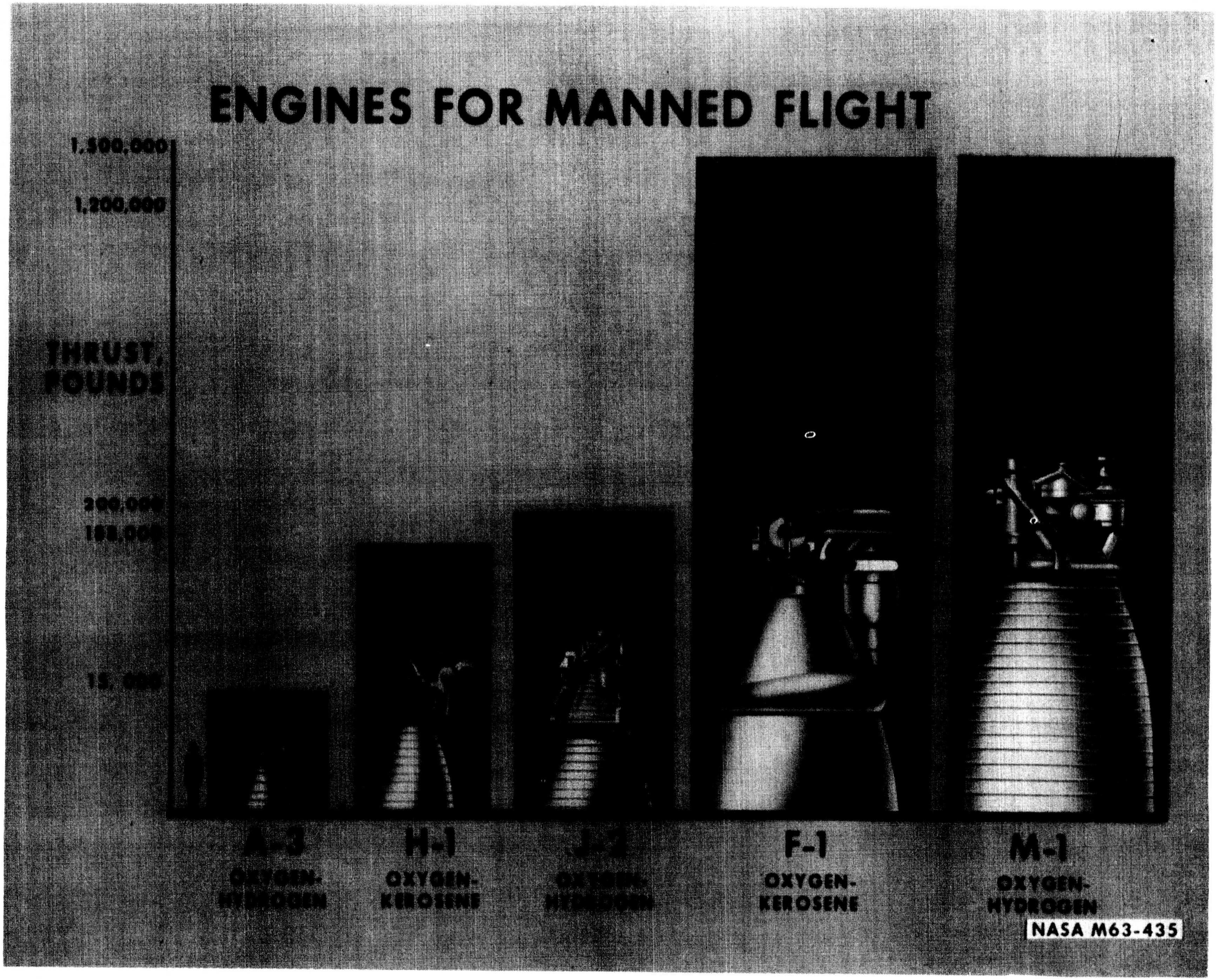
ENGINES FOR MANNED FLIGHT
1,500,000
1,200,000
THRUST, POUNDS
200,000
188,000
15,000
A-3
OXYGEN-HYDROGEN
H-1
OXYGEN-KEROSENE
J-2
OXYGEN-HYDROGEN
F-1
OXYGEN-KEROSENE
M-1
OXYGEN-HYDROGEN
NASA M63-435

Figure 3

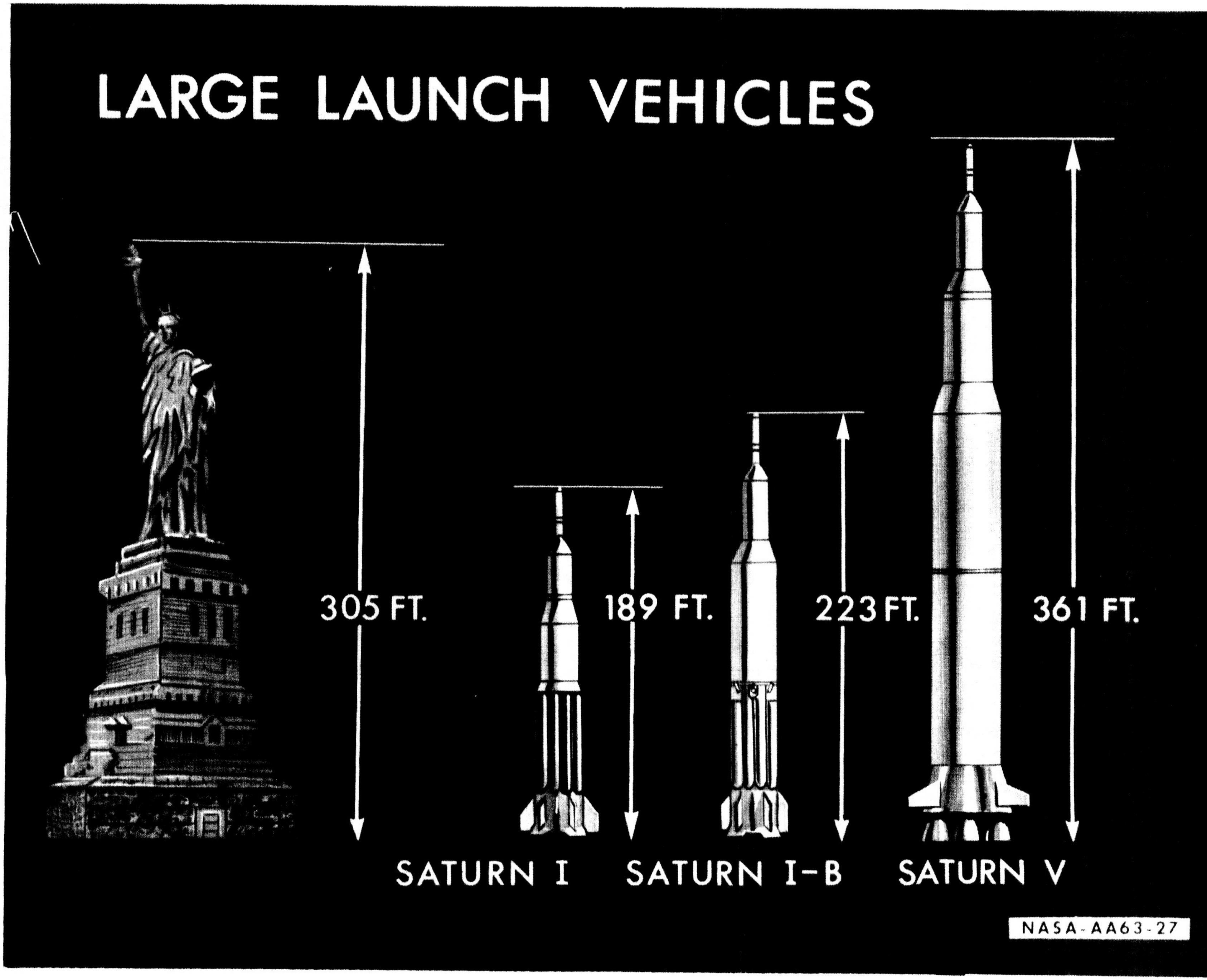
LARGE LAUNCH VEHICLES
305 FT.
189 FT.
223 FT.
361 FT.
SATURN I
SATURN I-B
SATURN V
NASA-AA63-27

Figure 4

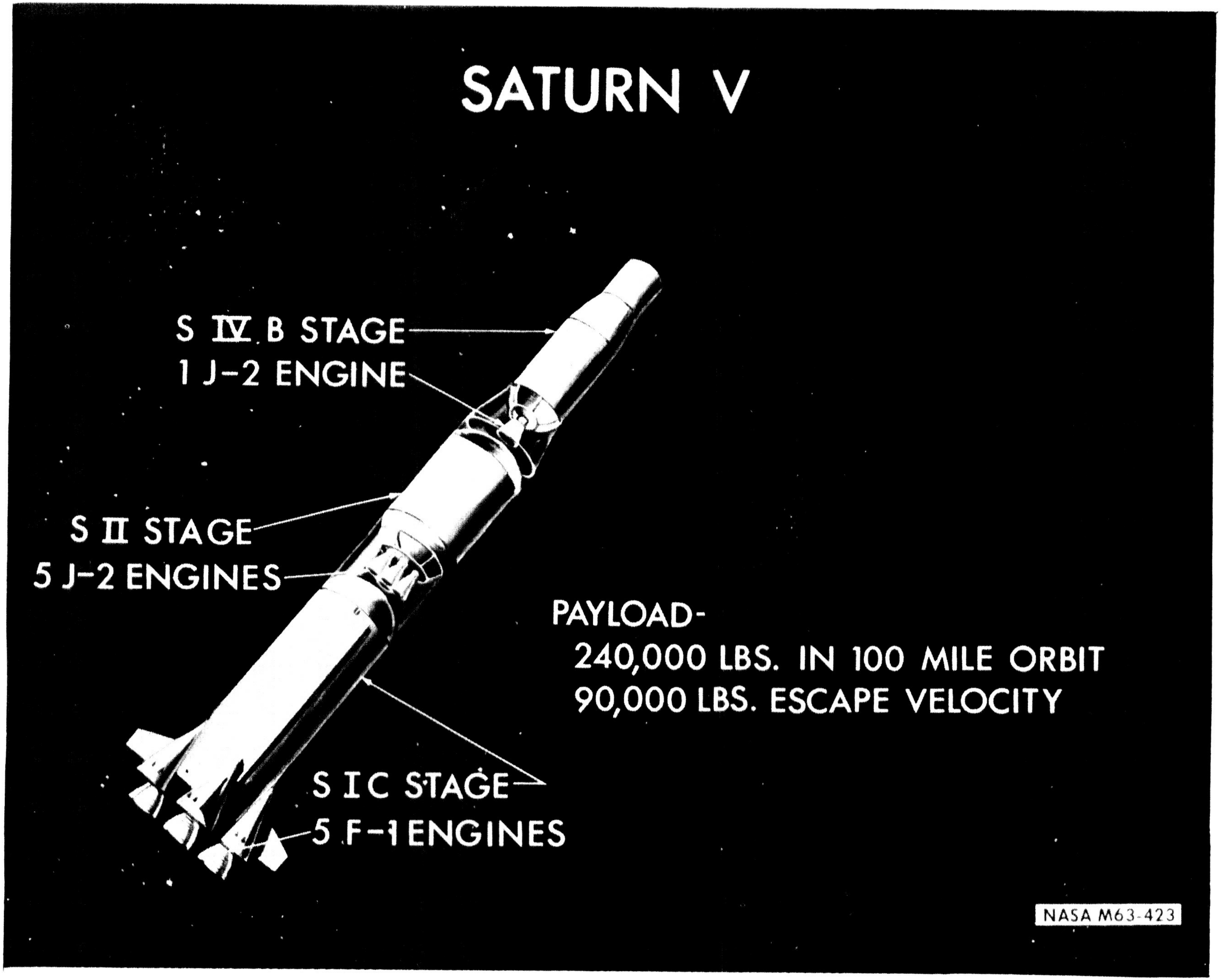
SATURN V
S IV B STAGE
1 J-2 ENGINE
S II STAGE
5 J-2 ENGINES
S I C STAGE
5 F-1 ENGINES
PAYLOAD-
240,000 LBS. IN 100 MILE ORBIT
90,000 LBS. ESCAPE VELOCITY
NASA M63-423

Figure 5

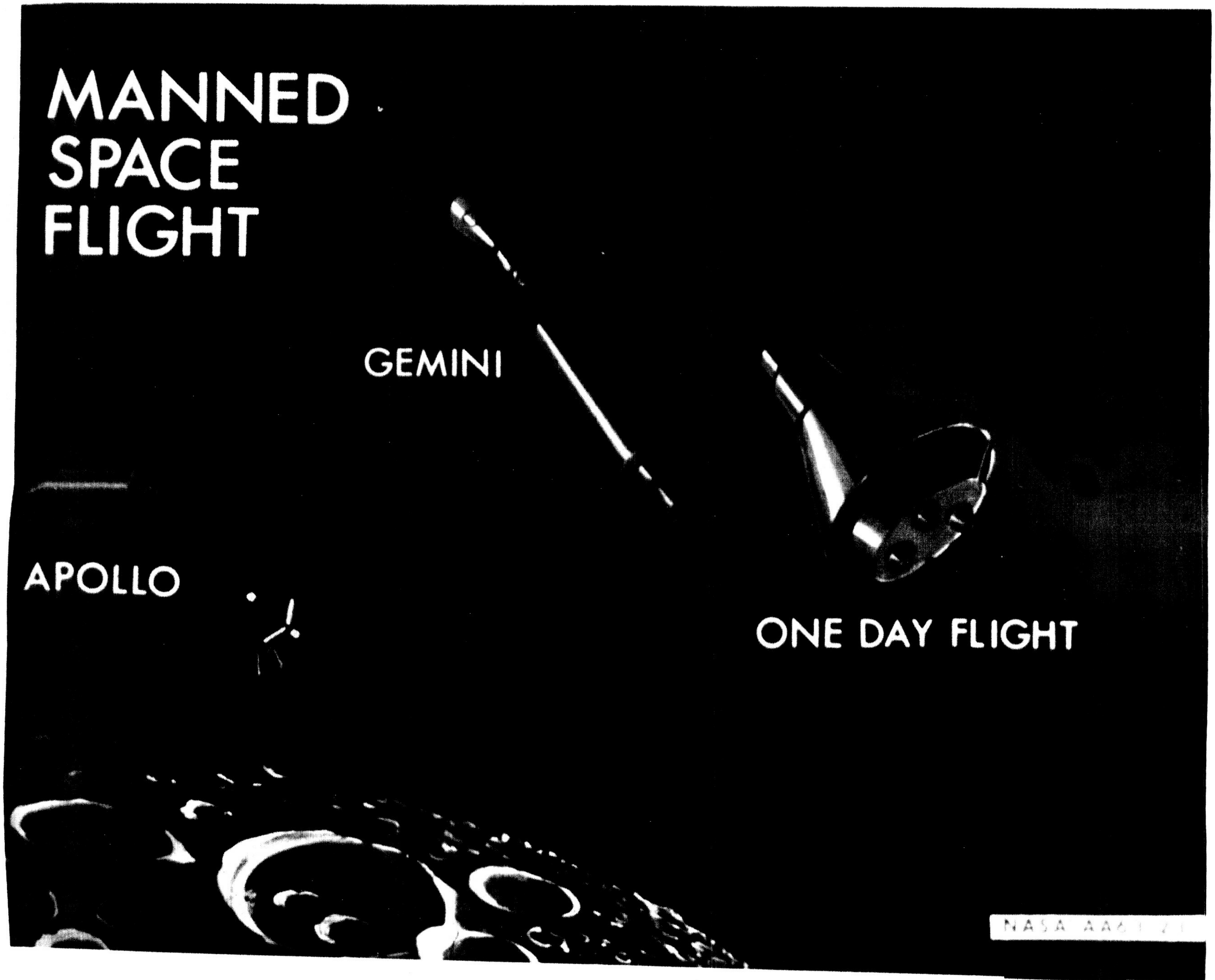

Figure 6

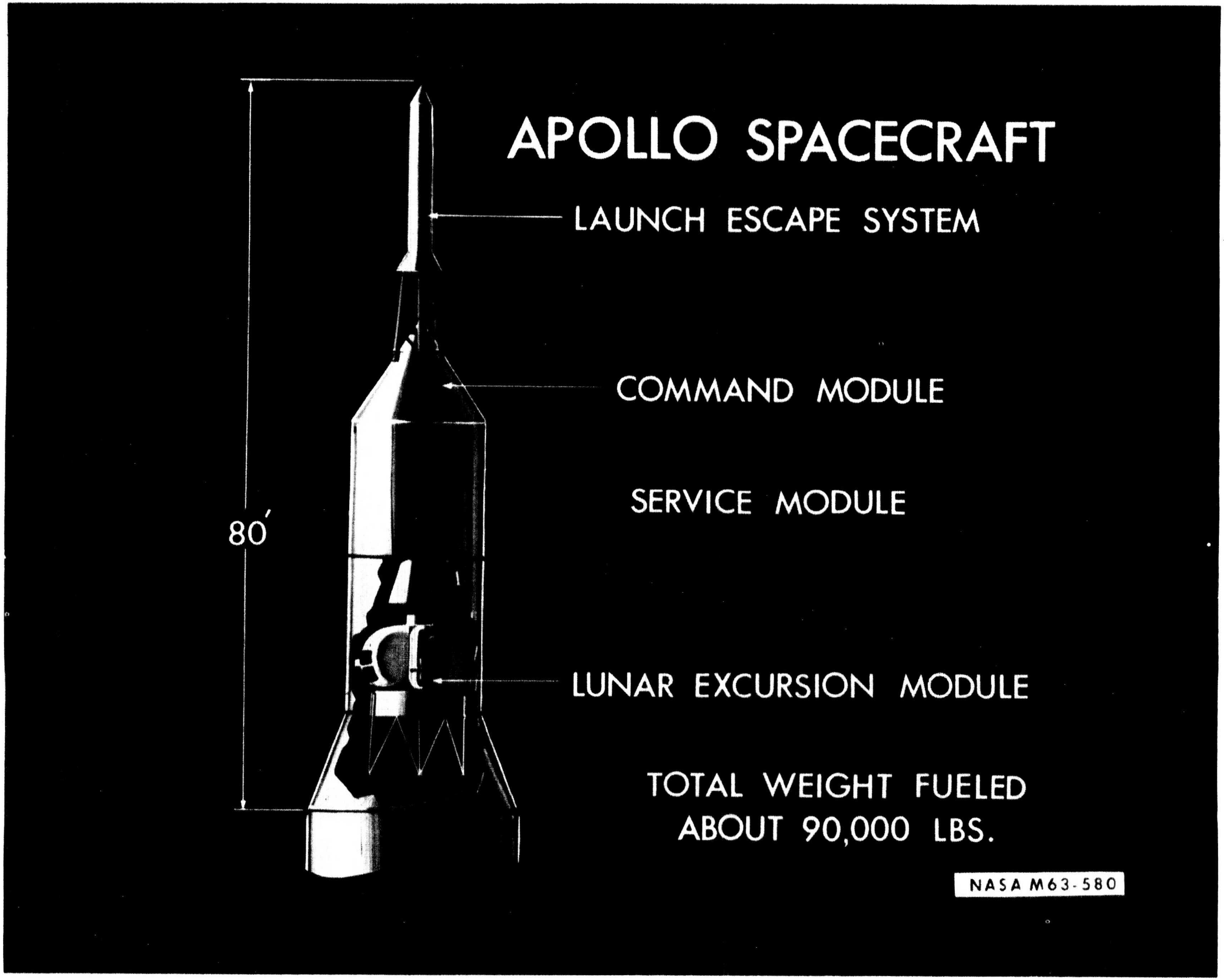
APOLLO SPACECRAFT
LAUNCH ESCAPE SYSTEM
COMMAND MODULE
SERVICE MODULE
LUNAR EXCURSION MODULE
80′
TOTAL WEIGHT FUELED
ABOUT 90,000 LBS.
NASA M63-580

Figure 7

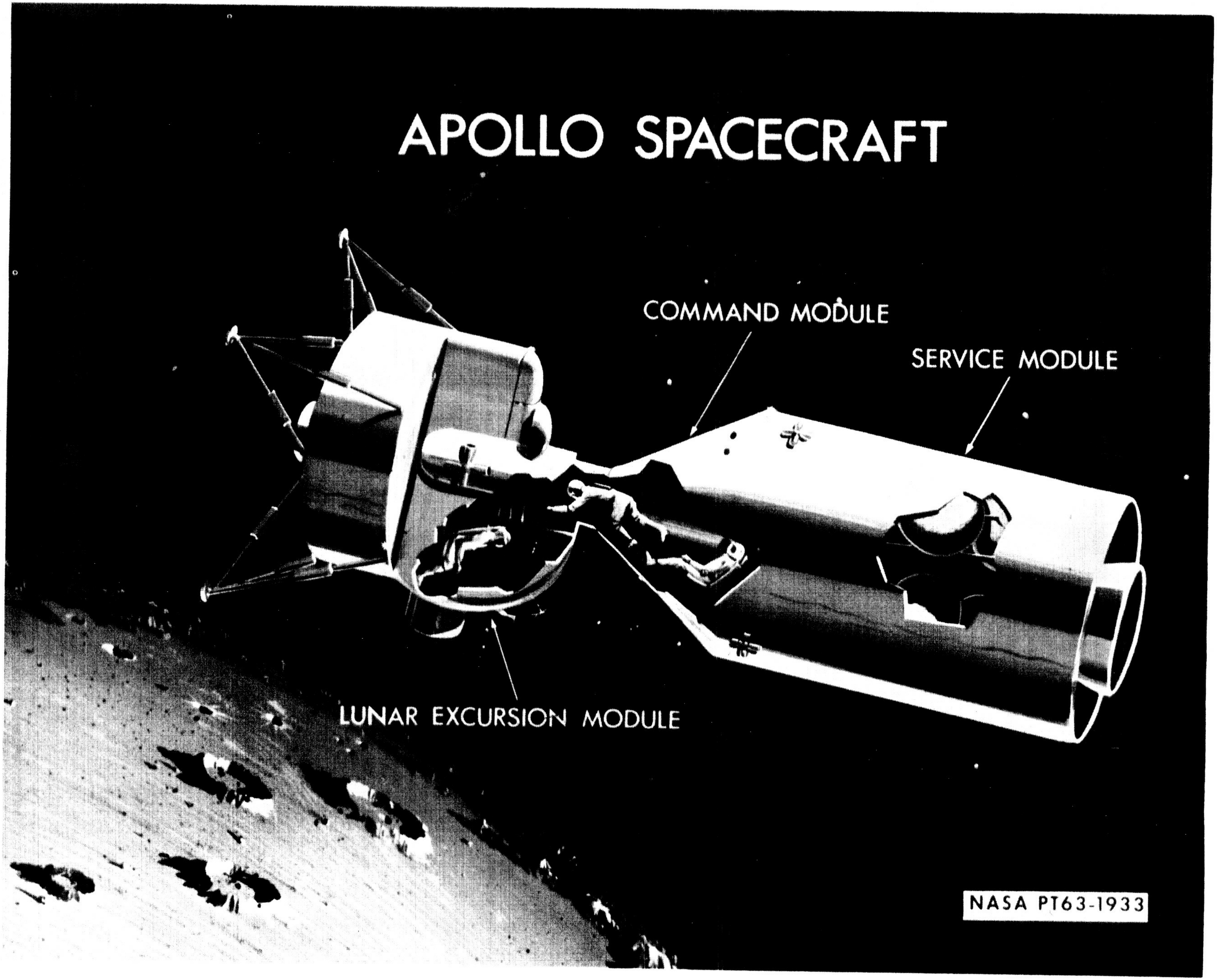
APOLLO SPACECRAFT
COMMAND MODULE
SERVICE MODULE
LUNAR EXCURSION MODULE
NASA PT63-1933

Figure 8

Figure 9

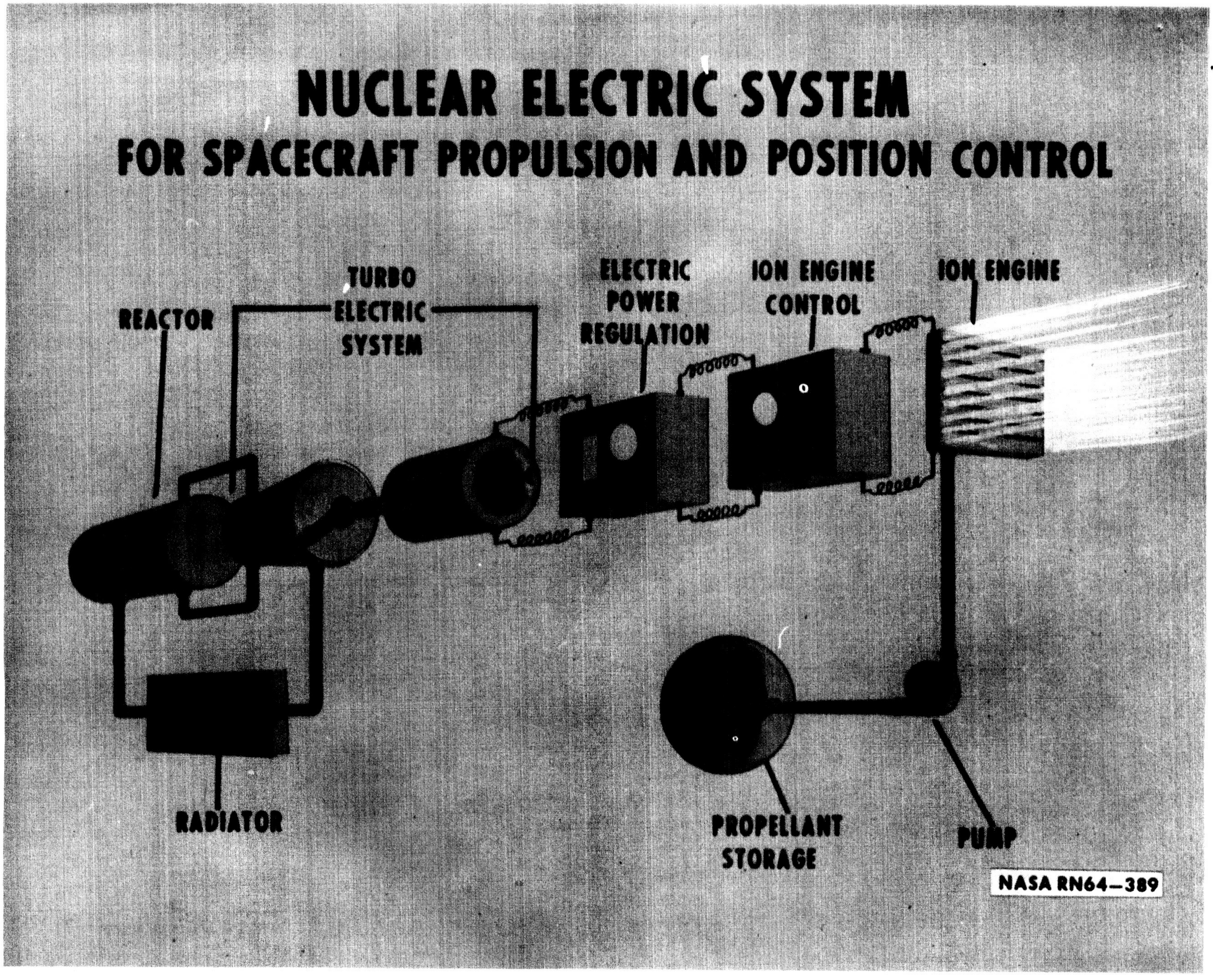
NUCLEAR ELECTRIC SYSTEM
FOR SPACECRAFT PROPULSION AND POSITION CONTROL
REACTOR
TURBO ELECTRIC SYSTEM
ELECTRIC POWER REGULATION
ION ENGINE CONTROL
ION ENGINE
RADIATOR
PROPELLANT STORAGE
PUMP
NASA RN64—389

Figure 10

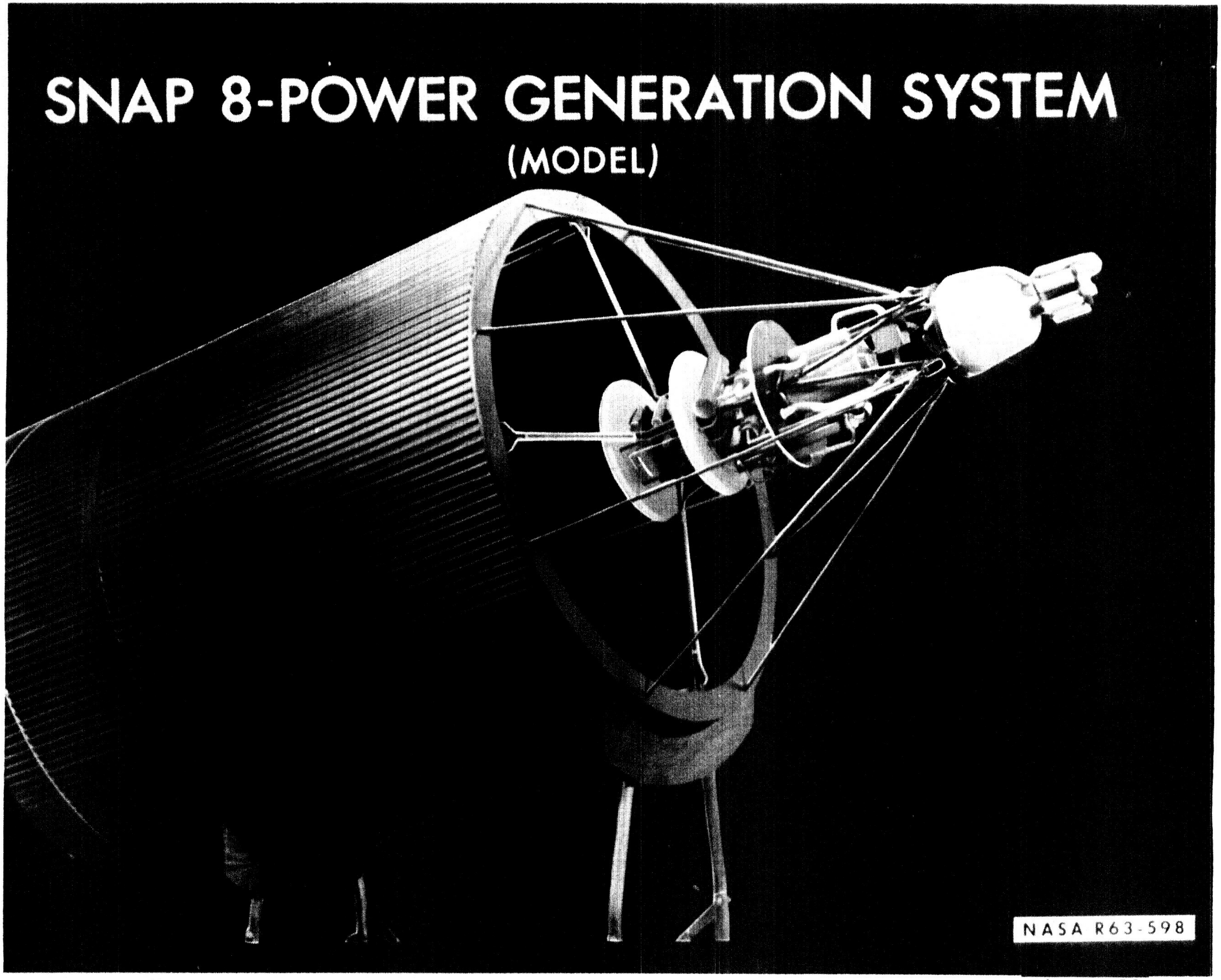

Figure 11

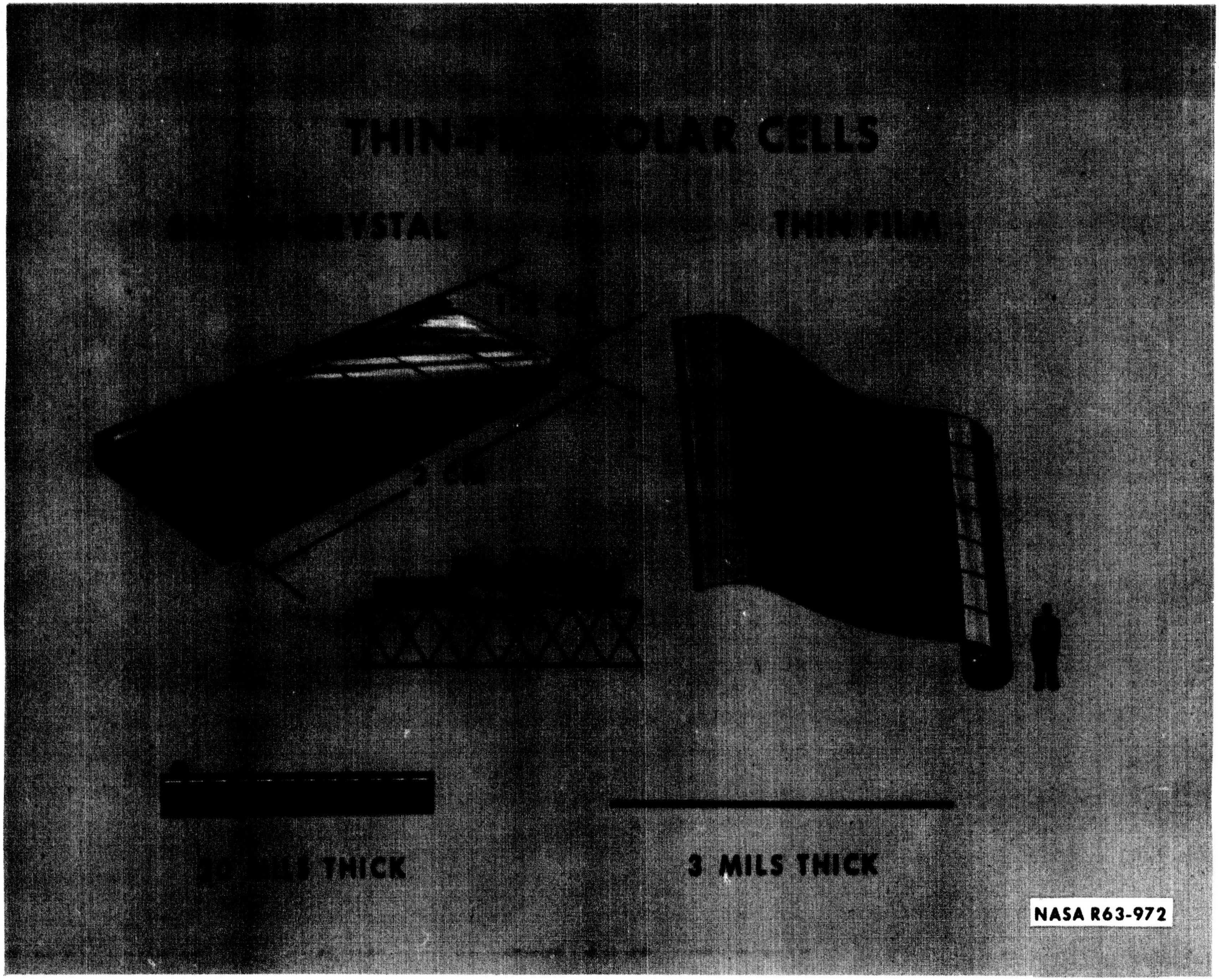

Figure 12

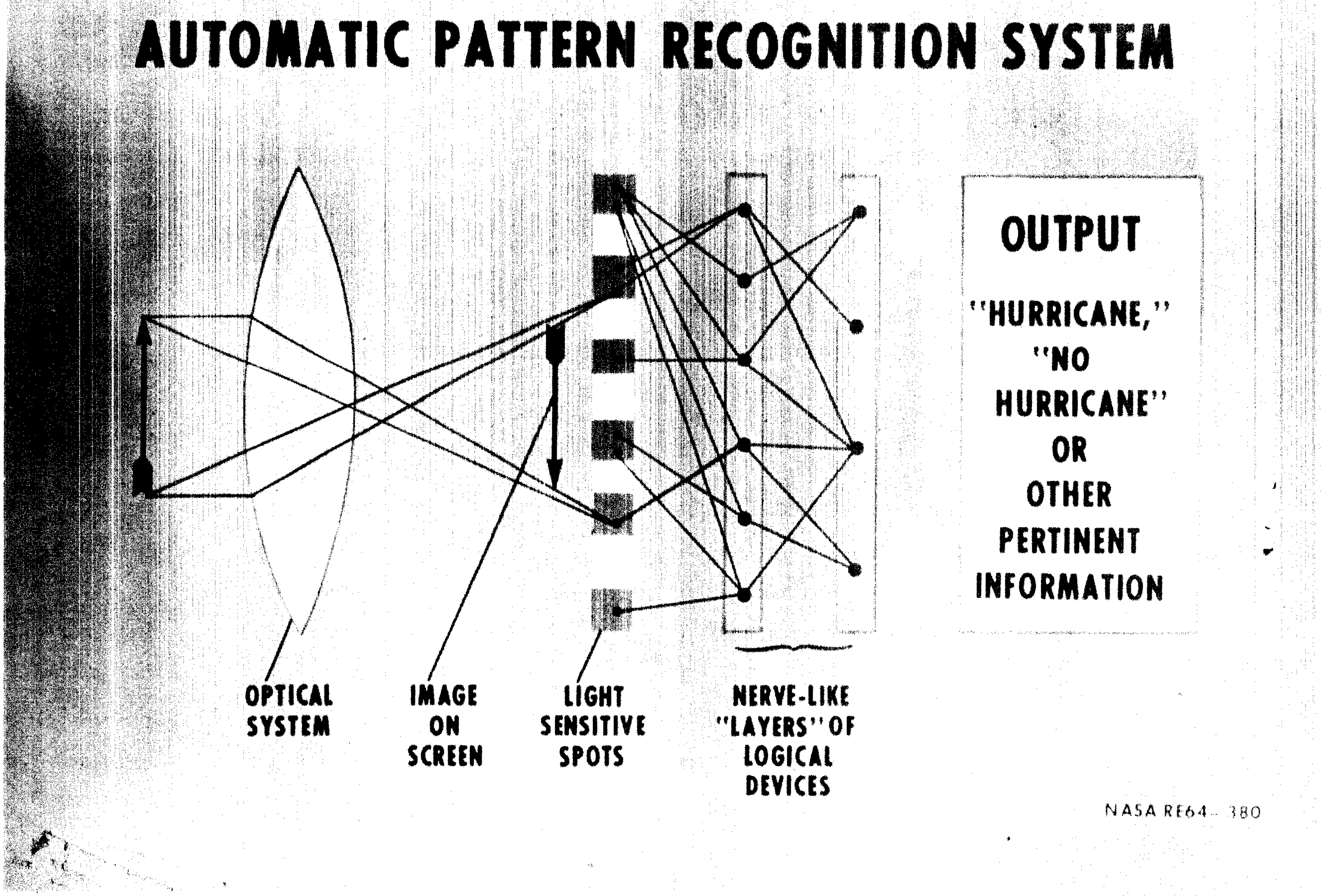
AUTOMATIC PATTERN RECOGNITION SYSTEM
OPTICAL SYSTEM
IMAGE ON SCREEN
LIGHT SENSITIVE SPOTS
NERVE-LIKE "LAYERS" OF LOGICAL DEVICES
OUTPUT
"HURRICANE," "NO HURRICANE" OR OTHER PERTINENT INFORMATION
NASA RE64-380

Figure 13